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A Study of the Conditions Governing an Electrification of the Champaign-Chicago Division of the Illinois Central Railroad

Railway Electrical Engineering

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A STUDY OF THE CONDITIONS GOVERNING AN ELECTRIFICATION OF THE CHAMPAIGN-CHICAGO DIVISION OF THE ILLINOIS CENTRAL RAILROAD

BY

JOHN MOFFAT FETHERSTON

AND

EDWARD MAX KRABBE

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

RAILWAY ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING

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JOHN MOFFAT FETHERSTON and EDWARD MAX KRABBE

ENTITLED A STUDY OF THE CONDITIONS GOVERNING AN ELECTRIFICATION OF THE CHAMPAIGN-CHICAGO DIVISION OF THE ILLINOIS CENTRAL RAILROAD

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF BACHELOR OF SCIENCE

in

RAILWAY ELECTRICAL ENGINEERING

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CHAPTER ONE

—

PRELIMINARY

The recent agitation for the electrification of the steam railroads within the city limits of Chicago and the success of the terminal electrifications of several of the largest eastern roads, has caused the Illinois Central Railway Company to consider seriously the substitution of electricity for steam, as motive power for its Chicago terminal.

In the rapid growth and development of the city of Chicago little thought was given for the future and it was not until two years ago that the extreme congestion of the business district, especially that portion of it which is known as the "loop", was realized. An inspection of the map of Chicago will show that the business district is closely surrounded by the terminals and freight yards of the railroads which enter the city. These have grown up with the development of the city, additions being made as conditions demanded; and as a result a very tangled and inefficient network of railroad tracks has resulted. The city of Chicago has finally awakened to the fact that it must increase the area

of its business district; and with this idea in view it has drawn up plans by which it will attempt to force the railroads to reduce the area of their yards and terminals, within the city limits, and to use them more efficiently. As the limit of the capacity of steam operation has already been reached, this will mean that the railroads will have to electrify their their tracks within the municipal limits.

Owing to the fact that electrifications of short portions of steam railroads, such as terminals, even though successful, are extremely costly both in installation and operation, and to the fact that the great density of traffic between Champaign and Chicago makes this road division most suitable for electrification, this thesis will consider the electrifying of the Illinois Central Railroad betweeen Champaign and the Chicago Terminal at Twelfth Street.

The electrification of the terminals of the New York Central and the Pennsylvania Railroads in the city of New York has shown that a great increase in terminal and yard capacity can be secured by this method. The reduction in cost per train and passenger mile, the smaller maintenance cost, the more frequent and efficient suburban service and the fact that the traffic can be adjusted so as to make the load factor of the power plant high, which means low power cost, show that electrification is not only desirable but absolutely necessary.

The traffic that at present traverses the main line of the Illinois Central between Champaign and the

Chicago terminal will only be taken into consideration in this discussion. This traffic consists of the passenger traffic of the Illinois Central to Champaign; the Cleveland, Cincinnati, Chicago and St. Louis to Kankakee; and the Michigan Central to Kensington; also the freight service of the Illinois Central to Champaign. The yard and the suburban traffic within the city limits of Chicago will not be included, as the data in regard to this service was not available. The electrification of these latter portions of the division would be more profitable than for the main line, making the complete project even more favoralbe to electrify than the portion considered.

The question of a power plant has been considered, but after some study of the situation it has been found more economical not to erect any plant, but to purchase the power required for the electrified division from the Commonwealth Edison Company of Chicago. This decision has been reached for the following reasons:

1. The heavy freight traffic on this division is now operated at such times as will naturally make the load factor high, and the maximum load occurs at a time when the load on the Commonwealth Edison Company's power plant is low. By slight changes in the schedule the freight trains can be run on the division at such a time as will make the load factor a maximum; it can be further regulated so that the load peaks of the railway power will come at a time when the load on the city power plant is a minimum, thereby increasing the

the plant's load factor greatly. With this arrangement of power distribution, the railway load will be so low during the peak loads of the plant that little or no extra machinery will have to be installed by the Edison Company, in order to add the power requirements of the Illinois Central Railroad to the existing load. Therefore the fixed charges, which depend on the cost of purchase, installation, and maintenance of the machinery necessary to furnish the power, will be reduced to a minimum, which would be impossible to obtain if the railway company built and operated its own power plant. The cost of the purchased power in this case will be but little more than the cost of coal and attendance.

2. On November last, 1913, the city and elevated railways of Chicago renewed a contract with the Commonwealth Edison Company in which the power company agreed to furnish electrical energy to the railways at a price which is but little above the actual cost of its production. The rates at which this power is supplied are so low that it would be next to impossible for the railway company to secure power cheaper, or even as cheap, if it built and operated its own plant. A copy of a report of the above contract will be found in the Appendix, at the back of this thesis.

CHAPTER TWO

—

TRAFFIC

The traffic over this division was taken from the time-tables of the various railroads operating on this section of the Illinois Central. The passenger trains were left at their schedule time if they did not conflict with each other. If they did conflict the more important train was given the right-of-way and the other train was made to follow it a few minutes later. The weight of the Illinois Central passenger trains was taken from actual observation. The steel coaches were taken to average 70 tons each and the wooden coaches 50 tons each. From the data gathered the faster trains were found to average about 700 tons and the slower about 350 tons. The different roads that enter Chicago over the Illinois Central were taken as follows; the C.C.C.&St.L. enters the division at Kankakee and the Michigan Central enters at Kensington. It was assumed that the weight of the passenger trains of the above roads was the same as those of the Illinois Central.

The following are copies of the time-tables from which was obtained the necessary data for the passenger traffic:

PASSENGER TRAINS

—

ILLINOIS CENTRAL

SOUTHBOUND

TRAIN NO.	RUN CHICAGO TO	DISTANCE MILES	TIME LEAVE	TIME ARRIVE	ON ROAD HOURS
1	Champaign	126.38	9:10 A.M.	12:07 P.M.	4:00
3	"	"	6:35 P.M.	9:45 P.M.	3:10
5	"	"	2:40 A.M.	6:05 A.M.	3:25
9	"	"	8:15 P.M.	11:15 P.M.	3:00
21	"	"	8:20 P.M.	12:40 A.M.	4:20
23	"	"	7:30 A.M.	11:57 A.M.	4:27
25	"	"	5:20 P.M.	9:05 P.M.	3:45
31	Gilman	79.66	3:30 P.M.	7:00 P.M.	3:30
17	"	"	10:30 P.M.	12:43 A.M.	2:13
19	"	"	10:02 A.M.	12:04 P.M.	2:02

NORTHBOUND

	Chicago From				
2	Champaign	126.38	6:08 P.M.	9:30 P.M.	3:22
4	"	"	7:40 A.M.	11:00 A.M.	3:20
34	"	"	2:50 P.M.	7:30 P.M.	4:40
22	"	"	2:25 A.M.	6:15 A.M.	3:50
24	"	"	12:50 P.M.	4:15 P.M.	3:25

TRAIN NO.	RUN CHICAGO FROM	DISTANCE MILES	LEAVE	ARRIVE	TIME ON ROAD HOURS
26	CHAMPAIGN	126:38	8:10 A.M.	12:30 P.M.	4:40
10	"	"	4:38 A.M.	7:50 P.M.	3:12
32	GILMAN	79.66	6:20 A.M.	9:55 A.M.	3:35
18	"	"	4:30 A.M.	7:15 A.M.	2:45
20	"	"	4:25 P.M.	6:35 P.M.	2:10

C.C.C. & St.L.

SOUTHBOUND

	TO				
16	KANKAKEE	54.4	9:25 A.M.	11:00 A.M.	1:35
18	"	"	12:45 P.M.	2:16 P.M.	1:31
34	"	"	9:05 P.M.	10:50 P.M.	1:50
38	"	"	11:55 P.M.	1:30 P.M.	1:35
R.P.	"	"	10:15 P.M.	11:48 P.M.	1:33

NORTHBOUND

	TO				
15	CHICAGO	54.4	3:25 P.M.	5:00 P.M.	1.35
19	"	"	6:45 P.M.	8:15 P.M.	1:30
43	"	"	5:20 A.M.	7:10 A.M.	1:50
35	"	"	6:10 A.M.	7:45 A.M.	1:55
9	"	"	11:13 A.M.	12:30 P.M.	1:17
R.P.	"	"	5:35 A.M.	7:25 A.M.	1:50

MICHIGAN CENTRAL

TRAIN NO.	RUN CHICAGO TO	DISTANCE MILES	TIME LEAVE	TIME ARRIVE	ON ROAD HOURS
46	KENSINGTON	13.08	3:00 A.M.	3:35 A.M.	0:35
2	"	"	7:10 A.M.	7:45 A.M.	0:35
8	"	"	9:05 P.M.	9:35 P.M.	0:35
10	"	"	10:30 P.M.	11:05 P.M.	0:35
20	"	"	12:30 P.M.	1:05 P.M.	0:35
42	"	"	1:00 P.M.	1:30 P.M.	0:30
14	"	"	3:45 P.M.	4:10 P.M.	0:35
44	"	"	5:40 P.M.	6:10 P.M.	0:35
6	"	"	10:00 P.M.	10:35 P.M.	0:35
36	"	"	12:05 A.M.	12:40 A.M.	0:35
40	"	"	12:35 A.M.	12:55 A.M.	0:30
22	"	"			
18	"	"			

NORTHBOUND

	TO				
27	CHICAGO	13:08	10:10 A.M.	10:45 A.M.	0:35
9	"	"	11:15 A.M.	11:50 A.M.	0:35
17	"	"	1:25 P.M.	2:00 P.M.	0:35
5	"	"	7:55 P.M.	8:25 P.M.	0:35
13	"	"	2:55 P.M.	3:30 P.M.	0:35
45	"	"	4:45 P.M.	5:15 P.M.	0:30
19	"	"	7:10 P.M.	7:40 P.M.	0:30
23	"	"	8:20 P.M.	8:55 P.M.	0:35
47	"	"	9:05 P.M.	9:40 P.M.	0:35

TRAIN NO.	RUN TO	DISTANCE MILES	TIME LEAVE	TIME ARRIVE	ON ROAD HOURS
	CHICAGO				
43	"	13.08	12:45 P.M.	1:15 P.M.	0:30
41	"	"	6:25 A.M.	7:00 P.M.	0:35
37	"	"	6:45 A.M.	7:30 A.M.	0:35
7	"	"	6:55 A.M.	7:30 A.M.	0:35
3	"	"	7:50 A.M.	8:25 A.M.	0:35

*

FREIGHT TRAINS

—

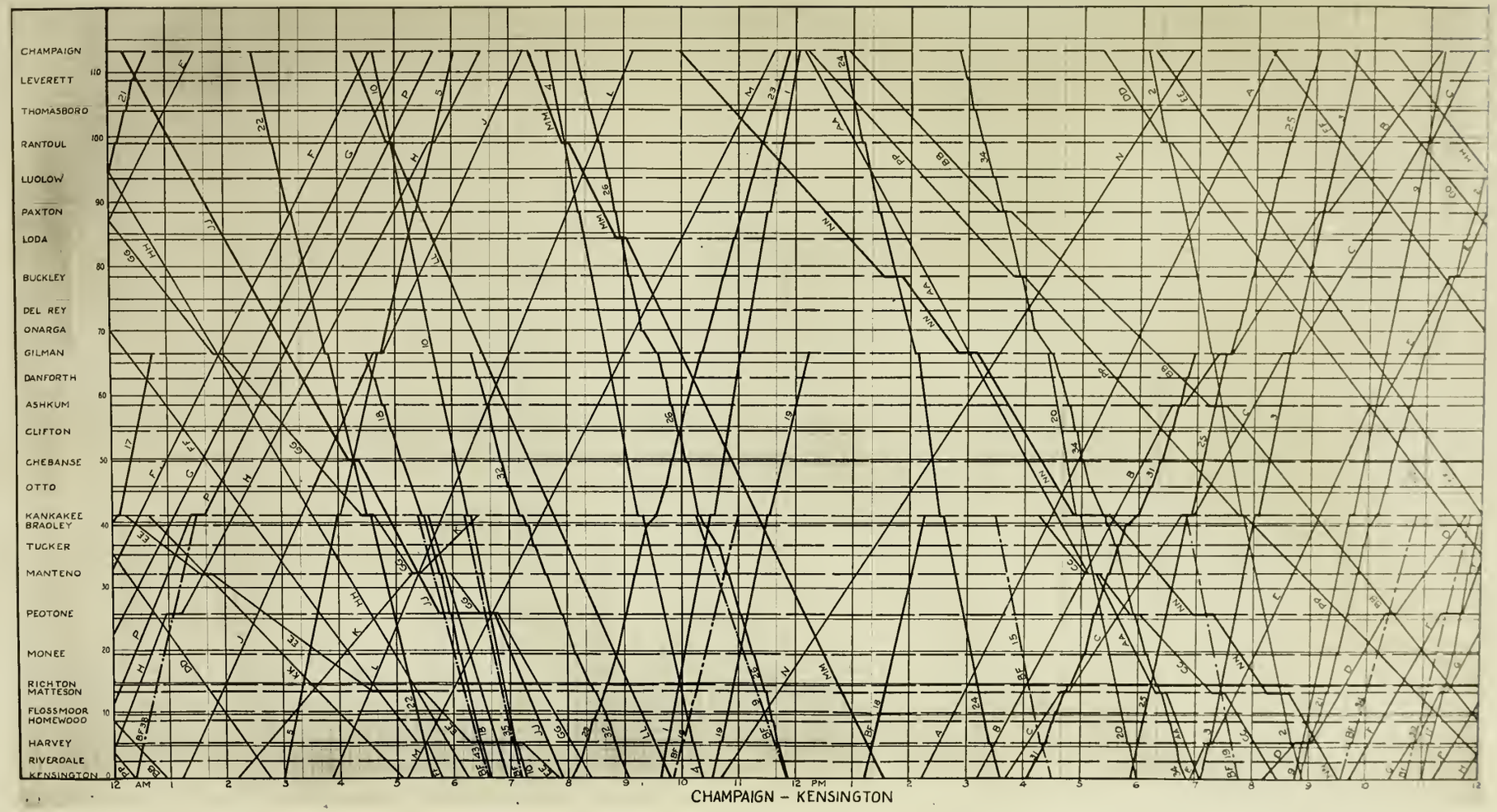
ILLINOIS CENTRAL

TRAIN NO.	RUN FORDHAM TO	DISTANCE MILES	WEIGHT TONS	TIME LEAVE	TIME ARRIVE	ON ROAD HOURS
A	CHAMPAIGN	115	1087	2:00 P.M.	8:20 P.M.	6:20
B	"	"	1510	3:00 P.M.	11:15 P.M.	8:15
C	"	"	835	3:30 P.M.	11:55 P.M.	8:25
E	"	"	1025	6:45 P.M.	1:30 A.M.	6:45
F	"	"	980	9:45 P.M.	4:30 A.M.	6:45
G	"	"	1805	10:15 P.M.	5:40 A.M.	7:25
H	"	"	1050	11:30 P.M.	6:30 A.M.	7:00
J	"	"	1200	1:00 A.M.	7:15 A.M.	6:15
L	"	"	950	3:40 A.M.	9:10 A.M.	5:30
M	"	"	1000	5:00 A.M.	11:40 A.M.	6:40
N	"	"	1750	10:30 A.M.	6:55 P.M.	8:25
P	"	"	1400	11:00 P.M.	5:40 A.M.	6:40

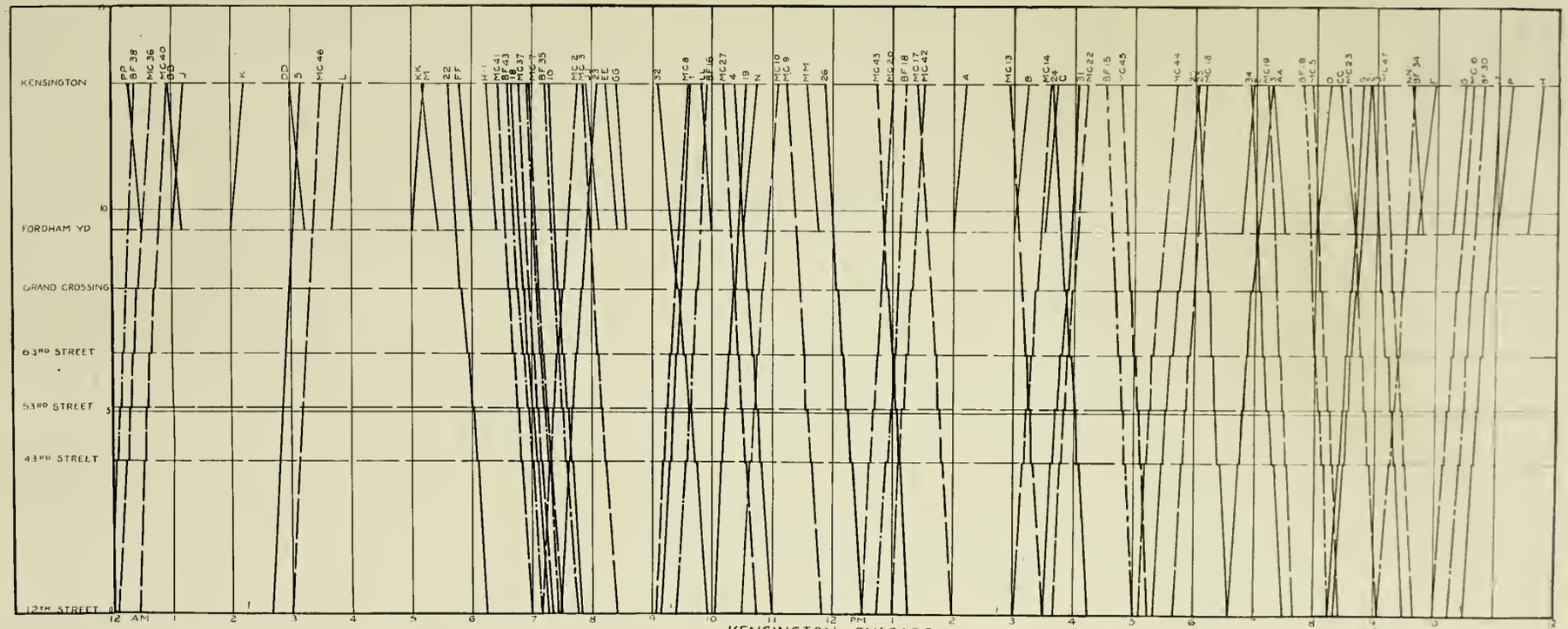
TRAIN NO.	RUN TO	DISTANCE MILES	WEIGHT TONS	TIME LEAVE	TIME ARRIVE	ON ROAD HOURS
	KANKAKEE					
D	"	72	765	8:00 P.M.	11:50 P.M.	3:50
K	"	"	1840	2:00 A.M.	6:30 A.M.	4:30
	CHAMPAIGN					
	TO					
AA	FORDHAM	115	1707	12:10 P.M.	7:15 P.M.	7:05
BB	"	"	3000	12:55 P.M.	1:10 A.M.	12:15
DD	"	"	2596	5:20 P.M.	3:15 A.M.	9:55
EE	"	"	3550	6:15 P.M.	8:25 A.M.	14:10
FF	"	"	2110	8:15 P.M.	6:00 A.M.	10:15
GG	"	"	2678	9:30 P.M.	8:35 P.M.	11:05
HH	"	"	1440	10:20 P.M.	6:25 A.M.	8:05
JJ	"	"	1675	12:15 A.M.	8:10 A.M.	7:55
LL	"	"	1440	4:15 A.M.	10:00 A.M.	5:45
MM	"	"	1235	7:20 A.M.	1:45 P.M.	6:25
NN	"	"	2960	10:00 A.M.	9:45 P.M.	11:45
PP	"	"	3485	12:15 P.M.	12:30 A.M.	12:15
	TO					
CC	KANKAKEE	"	1938	4:15 P.M.	8:40 P.M.	4:25
KK	"	"	1800	12:40 A.M.	5:20 A.M.	4:40

The time-sheets of the freight trains were made up from the data gathered during a twelve hour period of actual observation, at the north freight yards, Champaign, from 6 P.M. January 1st to 6 A.M. January 2nd, 1914. The actual weight of the trains, the number of the locomotive, the running time, together with the number and kind of cars were gotten during the observation period. The other twelve hours of the day were filled in so as to make the load peaks, caused by the heavy "drags", come during the night when the load on the Commonwealth Edison plant was a minimum. The number and size of the trains thus determined was found to check closely with the train-sheets at the railroad office of the above yards.

A graphic time-table was then drawn from the data obtained, time being taken as abscissa and distance as ordinates. This graph was drawn in two parts, the first being for that section of the road between Champaign and Kensington and the second for that section between Kensington and the Twelfth Street Terminal, Chicago. The passenger trains were first plotted on the charts and then the freight trains were drawn so that they did not conflict with them. In case of conflict the freight train was laid over on the nearest passing track until the superior train had gone by. This graphic time-table is a diagrammatic representation of the train movements over the division. On this chart the time of departure of a train, the time required for the run, the speed of the



CHAMPAIGN – KENSINGTON



KENSINGTON–CHICAGO

train at any point during the run, the length and number of stops, and the time of arrival of the train at its destination are shown by means of lines connecting the places between which the train runs. The time of arrival and departure of the train is shown by means of the time-abscissa. The time required for the run is determined by the length of the horizontal projection of the train-line joining the stations; as is also the length of the stops. The speed of the train is represented by the slope of the line, the steeper the line the greater is the train speed. On the ordinate of the chart the stations are marked and from this the train-stops can be determined. The number of stops is shown by the number of breaks in the train-line on the diagram. From these graphic time-tables the load diagram and the power consumption of the railroad were determined.

The ton-milage of the Illinois Central was calculated from the actual weight, the number of trains and distance traveled on the division.

DAILY TON-MILAGE OF TRAFFIC

PASSENGER TRAINS

ILLINOIS CENTRAL

BOUND	NUMBER OF SAME KIND	DISTANCE MILES	TONNAGE	TON-MILES
SOUTH	6	126.4	700	530,500
"	1	126.4	350	44,210
"	2	79.7	700	111,600
"	1	79.7	350	27,900
NORTH	5	126.4	700	443,500
"	2	126.4	350	88,500
"	1	79.7	700	55,790
"	2	79.7	350	55,790
		C.C.C.&St.L.		
SOUTH	3	54.4	700	114,200
"	2	54.4	350	38,100
NORTH	2	54.4	700	76,100
"	4	54.4	350	76,100
		MICHIGAN CENTRAL		
SOUTH	9	13.1	700	82,500
"	4	13.1	350	18,360
NORTH	7	13.1	700	64,220
"	7	13.1	350	32,100
				2,359,630

FREIGHT TRAINS

ILLINOIS CENTRAL

BOUND SOUTH	DISTANCE MILES	TONNAGE	TON-MILES
"	117	1087	127,050
"	"	1510	176,850
"	"	835	97,600
"	"	1025	119,950
"	"	980	114,950
"	"	1805	210,600
"	"	1050	122,900
"	"	1200	140,450
"	"	950	111,100
"	"	1000	117,000
"	"	1750	204,800
"	"	1400	163,950
"	72	765	55,050
"	"	1840	132,650
		TOTAL	1,894,700

BOUND NORTH	DISTANCE MILES	TONNAGE	TON-MILES
"	117	1707	199,700
"	"	3000	351,000
"	"	2596	304,000
"	"	3550	415,050
"	"	2110	246,900
"	"	2678	313,600
"	"	1440	168,600
"	"	1675	196,000
"	"	1440	168,450
"	"	1235	144,350
"	"	2960	346,100
"	"	3485	405,000
"	"	1880	220,000
"	54	1938	104,750
"	"	1800	97,200
		TOTAL	3,680,700

Daily ton-milage	7,935,030
Yearly ton-milage	2,699,185,950
Yearly locomotive milage	6,366
Average weight of locomotive, assumed, tons	175
Yearly locomotive ton-milage	1,114,050
Yearly locomotive and train ton-milage	2,700,300,000

From the Illinois Central annual statement on the performance of locomotives for the year ending June 30, 1909, (the latest year for which the information is available), the gross freight ton-miles for the Chicago division was 3, 266,368,779. In the passenger service there was a train-milage of 2,994,667. The average cars per train-mile were 5.47, and the average car weight was 60 tons. This gives a total passenger ton-milage of 982,252,991. The total annual ton-milage for the Chicago division was 4, 249,221,770. From the profile map as issued by the chief engineer of Maintenance of Way for the Illinois Central, Sept. 4th, 1907, the total miles of single track in the Chicago division was found to be 825 miles. The same report shows that the milage of the Champaign-Chicago section is 318 miles. The percentage of the Chicago division lying between Champaign and Chicago is 318/835 or 38% of the milage of the whole division. The total annual ton-milage for this section for the year 1909 was found to be 38% of 4,249,221,770 or 1,614,704,272 ton-miles. The calculated ton-milage for the year 1913 is approximately 2,700,000,000 ton-miles. The ratio of the calculated annual ton-miles for 1913 to the actual ton-miles for 1909 is 2,700,000,000/1,614, 704,272 or 167 per cent.

CHAPTER THREE

SYSTEMS OF ELECTRIFICATION

At the present time there is no general standard method of power distribution for electric railway operation. The generation of electricity at present is usually performed at any desired frequency and three-phase electromotive force. The power thus produced may be distributed to moving trains by several methods. Those in most general use are the direct-current system at trolley potentials of from 600 to 2400 volts; the three-phase system at from 3000 to 6600 volts; and the single-phase system at 6000 to 20000 volts. The principal characteristics of these systems are given in the following summary:

ADVANTAGES OF THE DIRECT-CURRENT SYSTEM:

The system is standardized for voltages up to 1500, and success has been obtained with even higher voltage installations.

Storage batteries may be used to smooth out the load on the power plant.

The transformers are placed in the rotary converter substations and not on moving cars or locomotives.

The series direct-current motor has been adopted because it has great tractive effort for starting trains or for running up grades. The tractive effort varies approx-

imately inversely as the speed, and thus the load on the motor and on the line is more uniform than would be the case if the tractive effort and the speed were maintained. Power is proportional to the product of the tractive effort and the speed. The speed-torque characteristics of the motors enable them to automatically protect themselves from electric heating, which varies as the square of the current input. Since the speed is not maintained with the tractive effort, the motor can be of smaller size, weight and cost for a given amount of required output. Only one trolley per track is required for the direct-current system, and the collectors are simple in design as well as being low in cost and efficient in service.

DISADVANTAGES OF THE DIRECT-CURRENT SYSTEM.

The efficiency of energy transmission is low, for the line-voltage is comparatively small, which causes large transmission, conversion and contact-line losses.

The substation and transformer equipment cost is high and their operation and maintenance is expensive.

Good speed control is difficult to obtain in this system and regeneration of energy is not practicable.

ADVANTAGES OF THE THREE-PHASE SYSTEM.

The efficiency of the three-phase motor is the highest obtainable; and the fact that commutators are not required makes them even more desirable.

For mountain divisions the constant speed characteristics of the motors and the great effieiency of

energy regeneration in this system are advantages which cannot be overlooked.

Energy can be restored to the line while braking with regenerative control and the number of wrecks can thus be reduced by the cutting down of the excessive wear on the brake shoes, breakage of the rigging and overheated wheel tires in heavy trains on long down grades.

Due to its high efficiency the weight of the three-phase motor is low, which reduces the weight of the supporting frames, the dead load hauled, the cost of the motors, and the cost of track maintenance.

Maximum torque may be obtained,from the start to full speed, which is a physical advantage in train acceleration.

DISADVANTAGES OF THE THREE-PHASE SYSTEM.

The double overhead trolley is not only dangercus and limited to low voltages; but it makes the contact-line construction costly and extremely difficult. The line voltage is limited to 6600 volts, due to the difficulty of insulating the trolley wires.

The motor characteristic curves are poor and the efficiency during acceleration is low. The draw-bar pull depends on the line pressure and the load factor of the equipment is low.

ADVANTAGES OF THE SINGLE-PHASE SYSTEM.

Simplicity governs the weakest part of the

system as only one trolley wire per track is necessary.

The energy required from the power plant is lowest due to the following reasons: The transmission line load factor is the highest obtainable. The load factor of the transformer substations is very high; because each substation reaches out and furnishes power to the diversified load of heavy individual train units, which are widely scattered. The load is therefore spread out and becomes uniform. The transmission and contact line losses are a minimum and the transformer facilities are perfect.

High efficiency is obtained during the train acceleration periods, and the motor potential can be varied without rheostatic losses by changing the relation of the primary and secondary taps on the transformer; thus giving a variable speed motor of high efficiency.

The draw-bar pull of the motors depends directly upon the applied potential and can therefore be kept at any desired value by adjusting the transformer taps.

The trolley voltages used are from 3000 to 20, 000 volts and therefore the line losses are the smallest of any system.

Transformer substations may be put at more distant intervals than in any other system; and the fact that they do not require an attendant is another large item in favor of the single-phase system.

DISADVANTAGES OF THE SINGLE-PHASE SYSTEM.

The great amount of material required for the

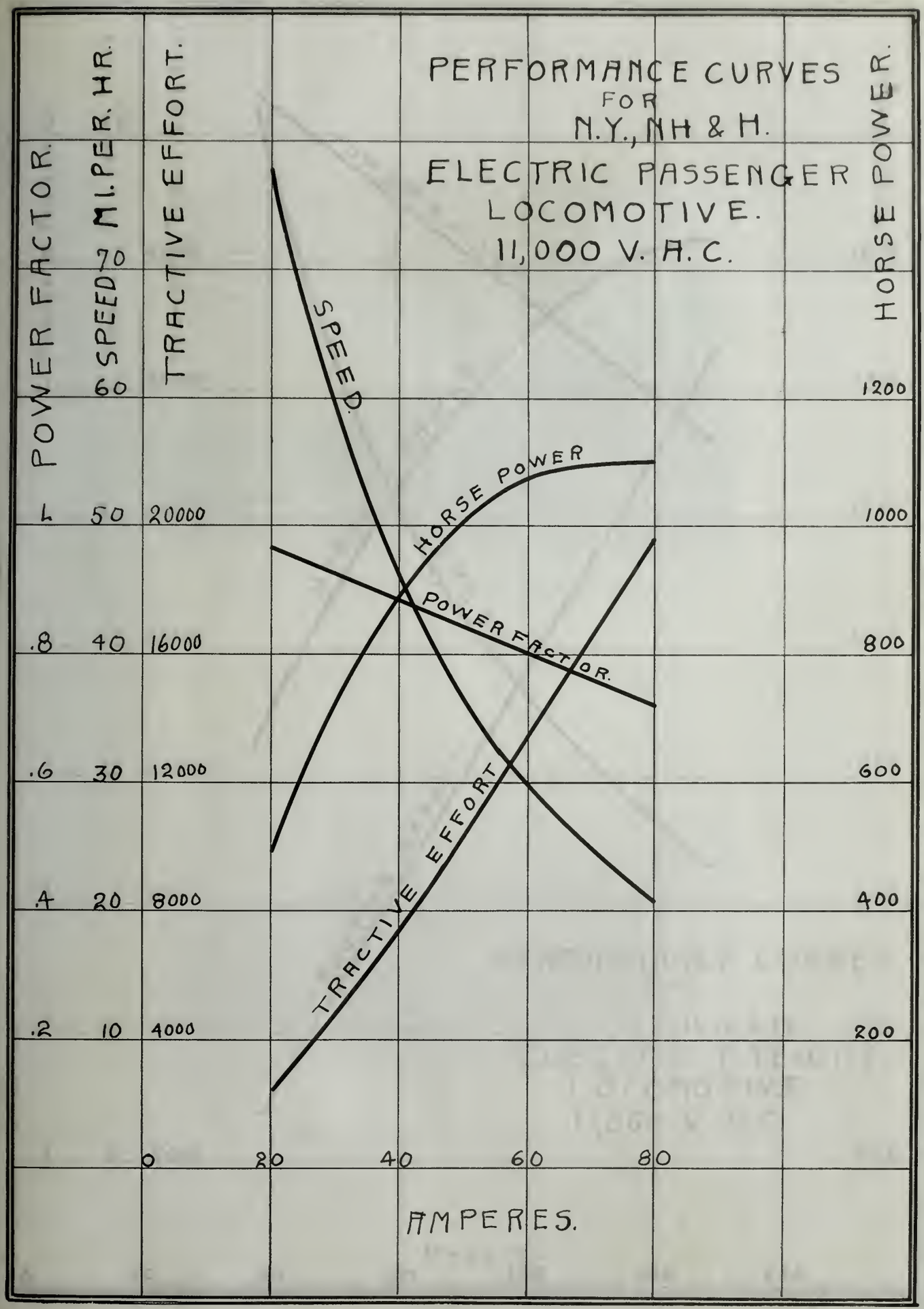
motors, the control and the transformers reduces the efficiency and increases the cost of the system.

After due consideration of the merits and disadvantages of the various electric systems used for heavy electric traction, it was decided to use the single-phase system of electrification on the Champaign-Chicago division of the Illinois Central Railroad; as the benefits and advantages to be obtained from this system far outweigh those of any other system when applied to this section of the road. Following a comparison of the different types and kinds of single-phase locomotives, by means of their characteristic curves, it was decided to use locomotives similar to those in operation on the New York, New Haven and Hartford Railroad at the present time. The passenger locomotives considered in this electrification will be of the "041" type, the freight of the "071" and the switcher of the "0300" type,; the specifications of which are shown in the table on page 375 of Burch's "Electric Traction For Railway Trains".

In choosing a system for the supporting of the contact line a comparison was made of the various forms of suspension used at the present time for single-phase heavy electric traction. The recent electrifications of steam railroads have proven that the catenary type of contact line suspension is the best for divisions where high speed passenger and heavy freight service predominate, as occurs on the Champaign-Chicago section of the Illinois Central. Of the various

systems of catenary construction, the experiments which have been made by the Pennsylvania Railroad on different kinds of contact lines, as reported in the Electric Railway Journal of April 18, 1914, show conclusively that the cross-catenary system of suspension is more than strong enough to meet the most severe conditions demanded by electric railroad service. The heavy bridge construction that was first installed by the New York, New Haven and Hartford on their electrified divisions has been proved unnecessary; because the cost of installation and maintenance is prohibitive and unwarranted, even for the heaviest traffic conditions. Therefore it was decided to use the cross-catenary type of contact line suspension in this electrification. The accompanying illustrations show clearly the system which has been chosen.

PERFORMANCE CURVES FOR N.Y., NH & H. ELECTRIC PASSENGER LOCOMOTIVE. 11,000 V. A.C.



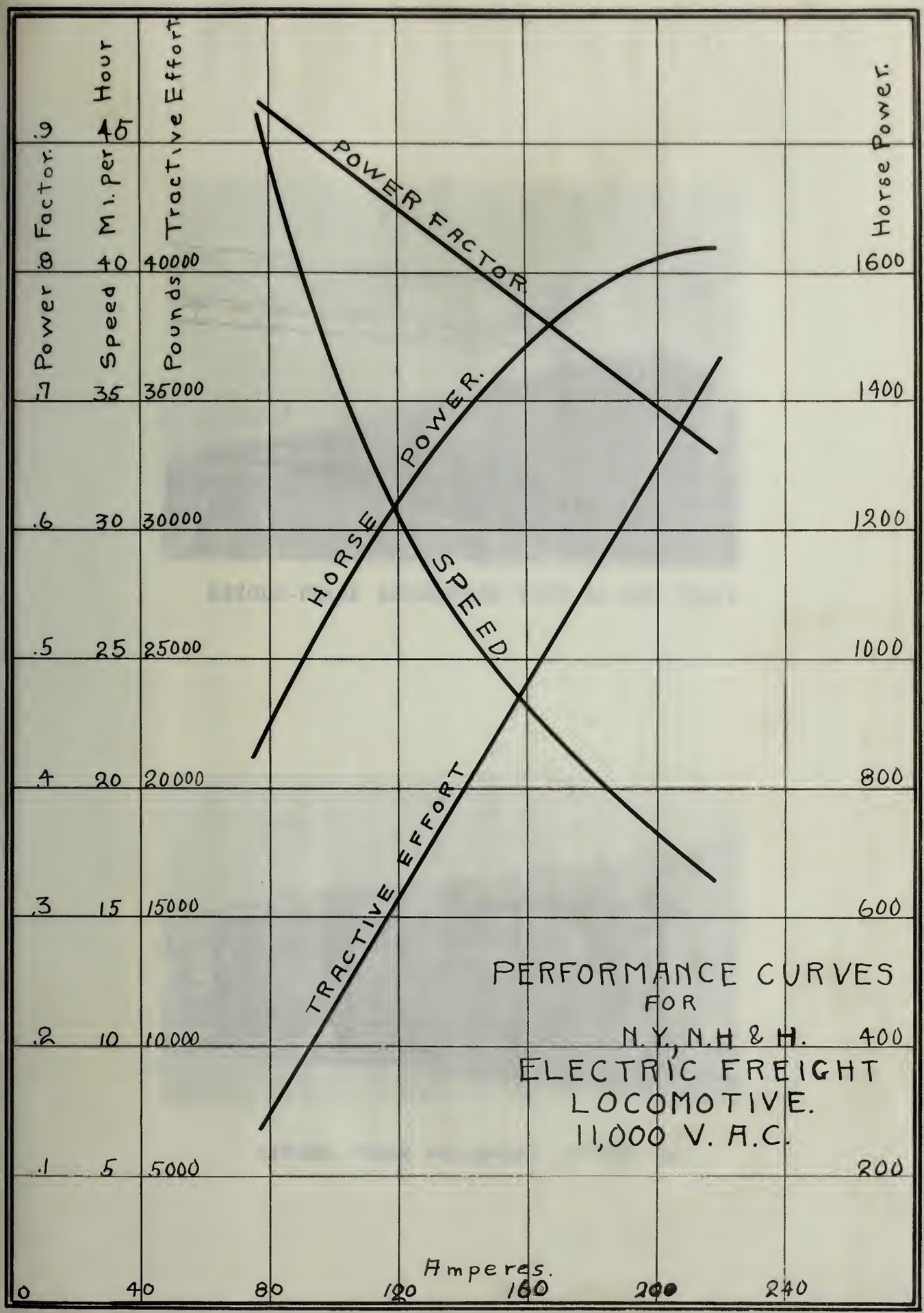
PERFORMANCE CURVES
FOR
N.Y.N.H. & H.
ELECTRIC PASSENGER
LOCOMOTIVE
11,000 V. A.C.

HORSE POWER

SPEED

TRACTIVE EFFORT

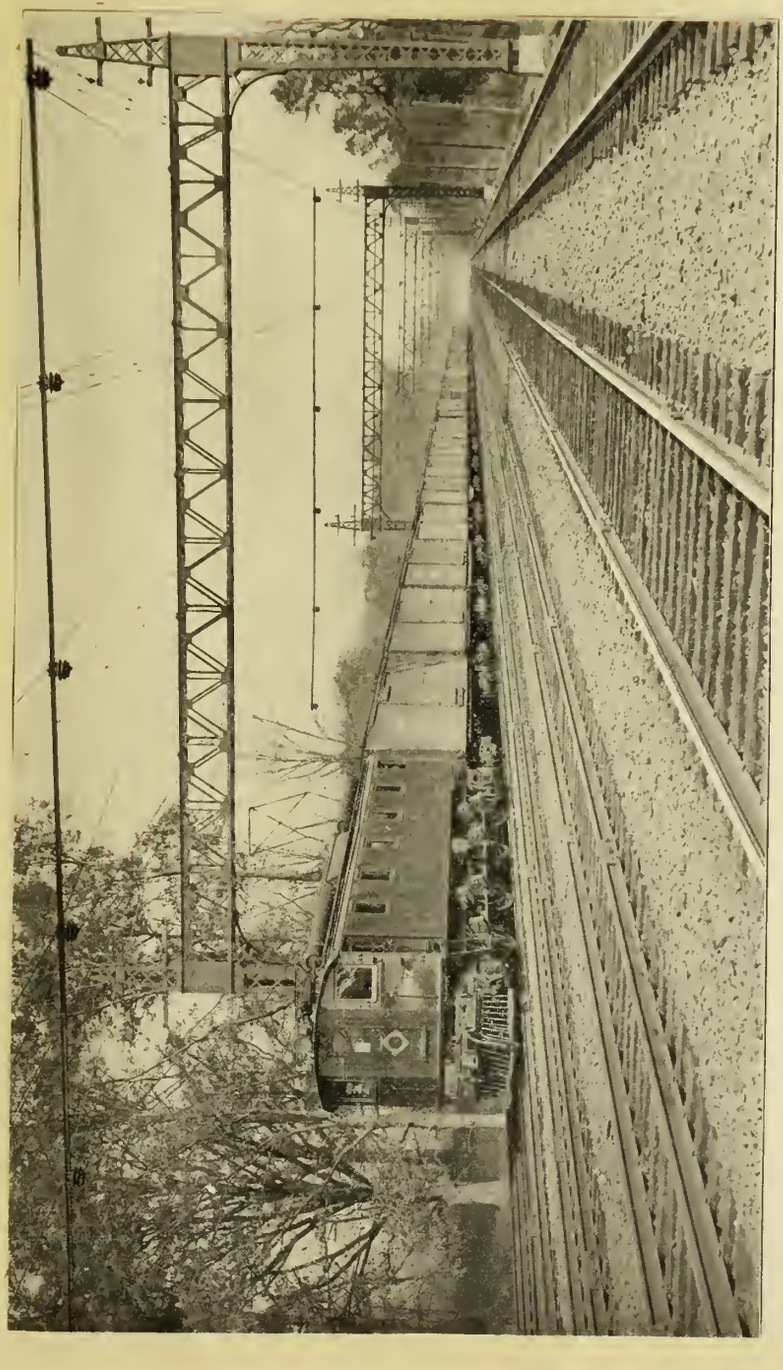
AMPERES


Power Factor.
Speed M. per Hour
Tractive Effort Pounds
Horse Power.
.9
.8
.7
.6
.5
.4
.3
.2
.1
40
40
35
30
25
20
15
10
5
40000
35000
30000
25000
20000
15000
10000
5000
1600
1400
1200
1000
800
600
400
200
POWER FACTOR
HORSE POWER.
SPEED.
TRACTIVE EFFORT
Amperes.
0
40
80
120
160
200
240
PERFORMANCE CURVES
FOR
N.Y., N.H & H.
ELECTRIC FREIGHT
LOCOMOTIVE.
11,000 V. A.C.

PERFORMANCE CURVES
FOR
D.Y.N.H & H
ELECTRIC FREIGHT
LOCOMOTIVE.
1,000 V. D.C.

SINGLE-PHASE LOCOMOTIVE WITH 12-CAR TRAIN

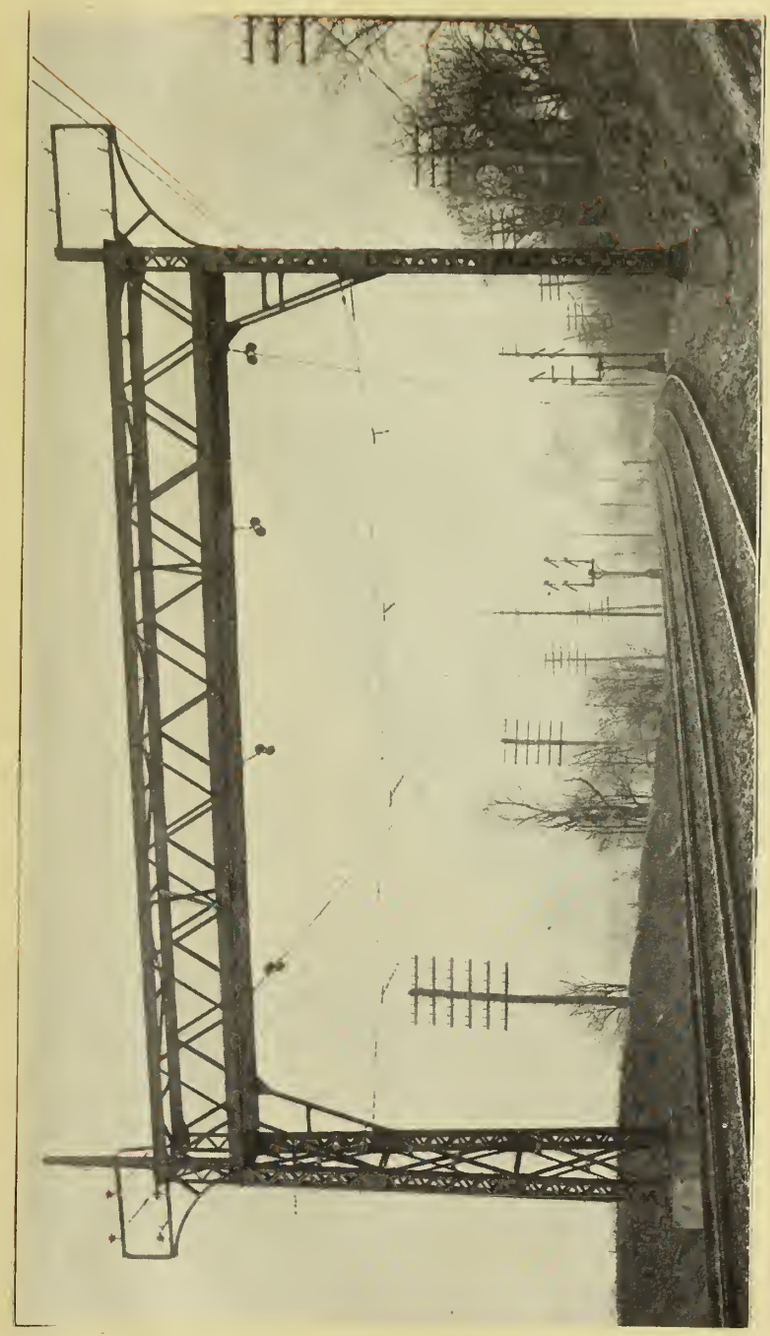
SINGLE-PHASE PASSENGER LOCOMOTIVE



Single Phase Electric locomotive and train, New York, New Haven & Hartford Railroad

CATENARY CONSTRUCTION ON CURVE OF PENN. RR. TEST.

CATENARY CONSTRUCTION ON PENNSYLVANIA RR. TEST SECTION.



TYPE OF ANCHOR BRIDGE ADOPTED BY THE PENNSYLVANIA RR.

CHAPTER FOUR

—

POWER REQUIRED FOR ELECTRIC OPERATION

After the train-charts had been drawn a load curve was made for the entire day. To get this load curve the trains were divided according to their weight, the passenger trains being divided into two classes 700 ton and 350 ton; the freight trains being separated into the following six classes 3050 ton, 1880 ton, 1740 ton, 1540 ton, 1370 ton, and 990 ton. Current-time diagrams were then drawn for each class of train. The acceleration and train resistance of the different trains were taken as follows:

TABLE OF TRAIN ACCELERATIONS

CLASS	WEIGHT TONS	SPEED MILES PER HOUR, AVERAGE	TRAIN RESISTANCE LBS. PER TON, AVERAGE	ACCELERATION M.P.H.P.SEC., AVERAGE
EXPRESS	700	25.0	7	0.30
LOCAL	350	27.0	7	0.45
FREIGHT	990	20.0	5	0.20
"	1370	20.3	5	0.20
"	1450	22.0	5	0.15
"	1740	17.0	5	0.10
"	1880	20.0	5	0.10
"	3050	25.0	5	0.10

The train resistance for the above trains was

taken from Prof. E.C. Schmidt's bulletin on train resistance. The reason why these rates of acceleration were chosen is because they are the highest that can be safely used and the greatest that the traffic will stand; these high rates being feasible only in electric operation.

A typical calculation for a current-time diagram is shown as follows, the 1880 ton freight train being used as an example :-

Acceleration is one mile per hour per second.

Train resistance is 5 pounds per ton.

Force required to accelerate the train to 0.1 mile per hour per second and to overcome the train resistance is 100 X .1 + 5 equals 15 pounds per ton.

Tractive effort necessary to start the train is 1880 X 15 or 28,200 pounds.

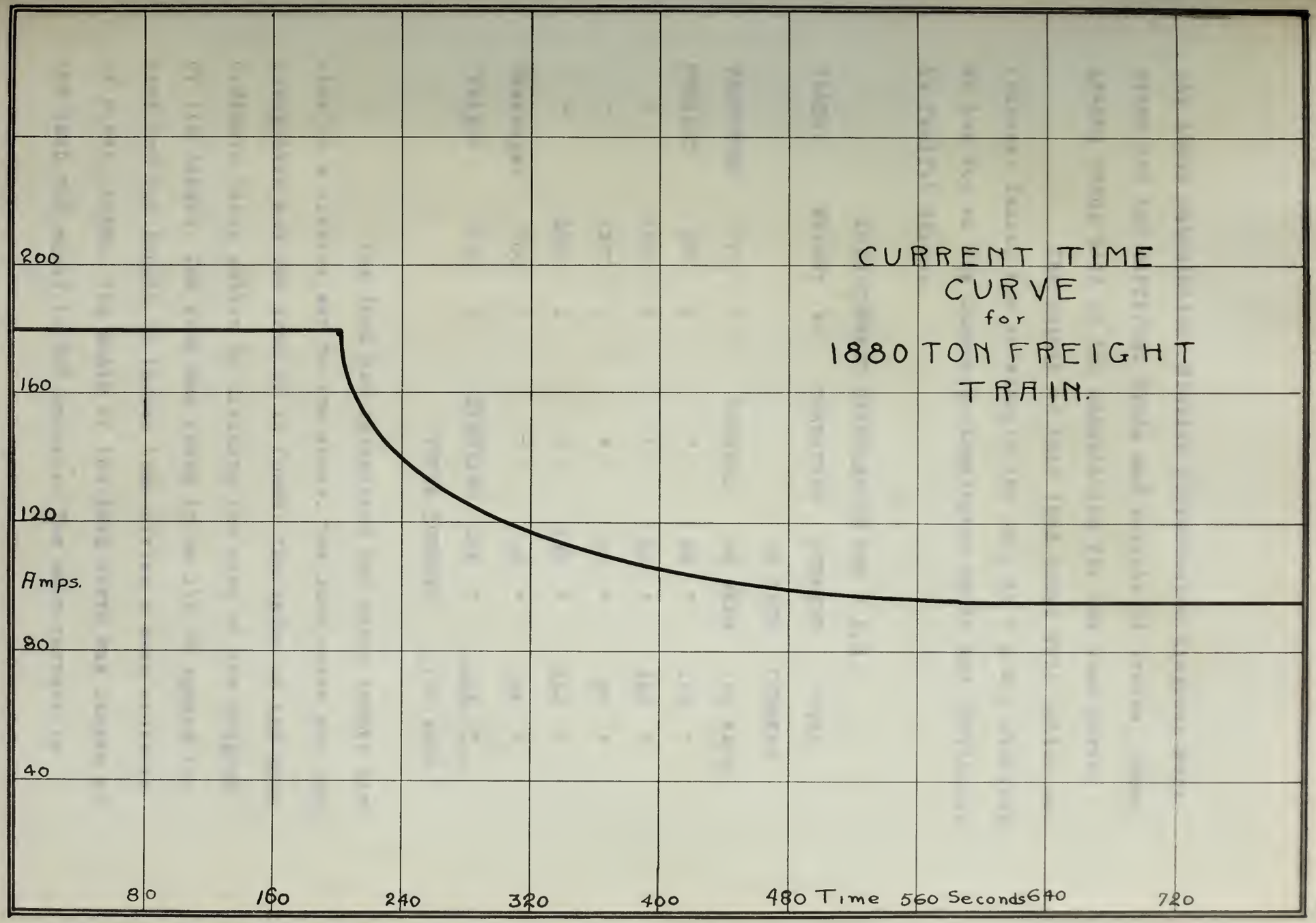
From the characteristic curve of the freight locomotive at 28,200 pounds tractive effort it requires 180 amperes at 11,000 volts and one locomotive unit.

The average speed is 20 miles per hour.

Time required to accelerate the train to 20 miles per hour is 20/.1 or 200 seconds.

The limiting speed is when the tractive effort equals the train resistance, this occurs at a speed of 38 miles per hour, the current being at 38 amperes.

The accompaning current-time diagram is for the 1880 ton freight train, which was used as an example in


CURRENT TIME
CURVE
for
1880 TON FREIGHT
TRAIN.
200
160
120
Amps.
80
40
80
160
240
320
400
480 Time
560 Seconds
640
720

CURRENT TRANSFORMER
CURVE
1000/1 TAP
ACCURACY CLASS 0.5
BURDEN IN OHMS
0.1
0.2
0.5
1.0
2.0
5.0
100
200
300
400
500
600
700
800
900
1000
1100
1200

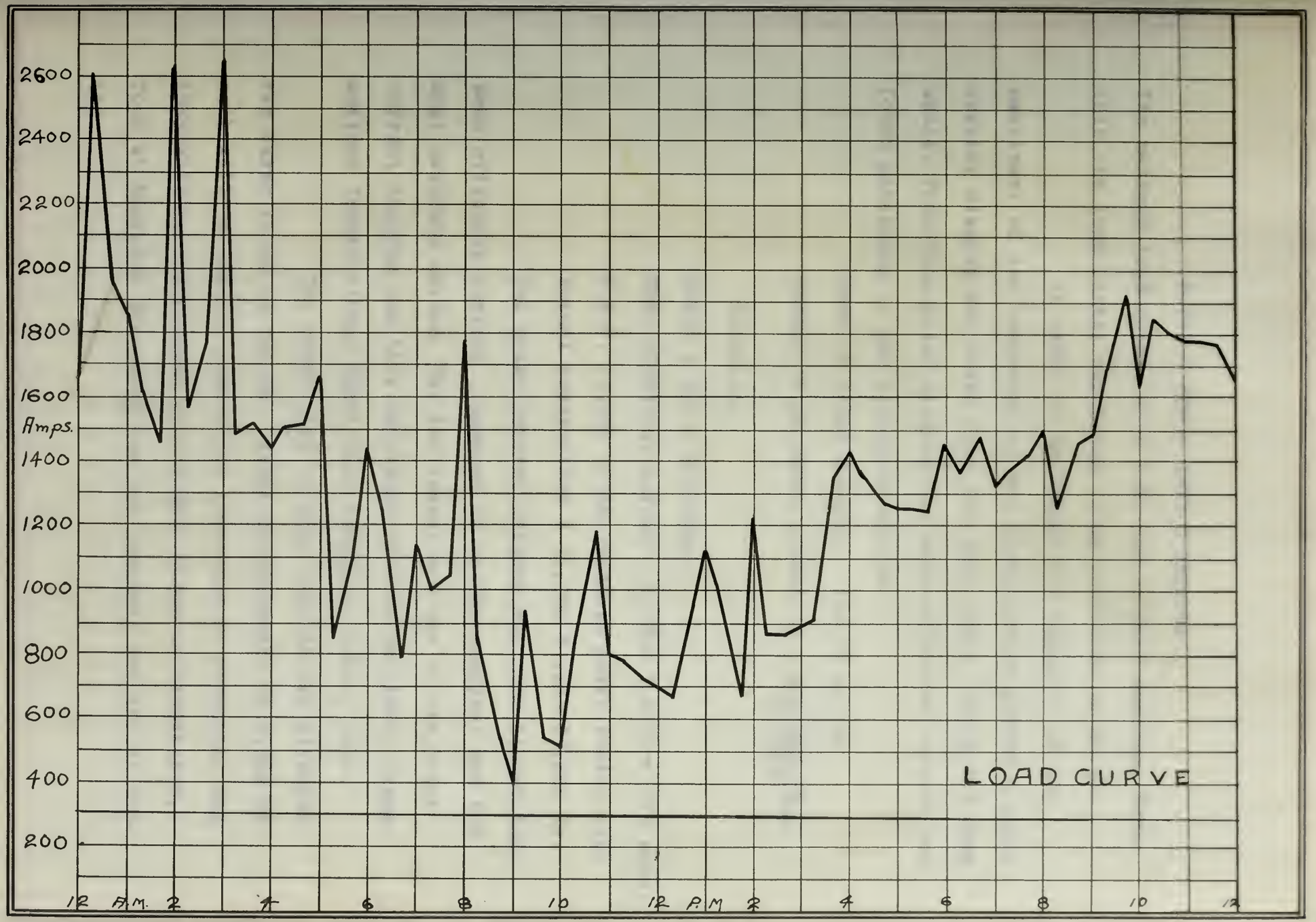
the above calculation. Similar current-time diagrams were drawn for the different kinds and weights of trains, these graphs being used in the calculation for the load curve.

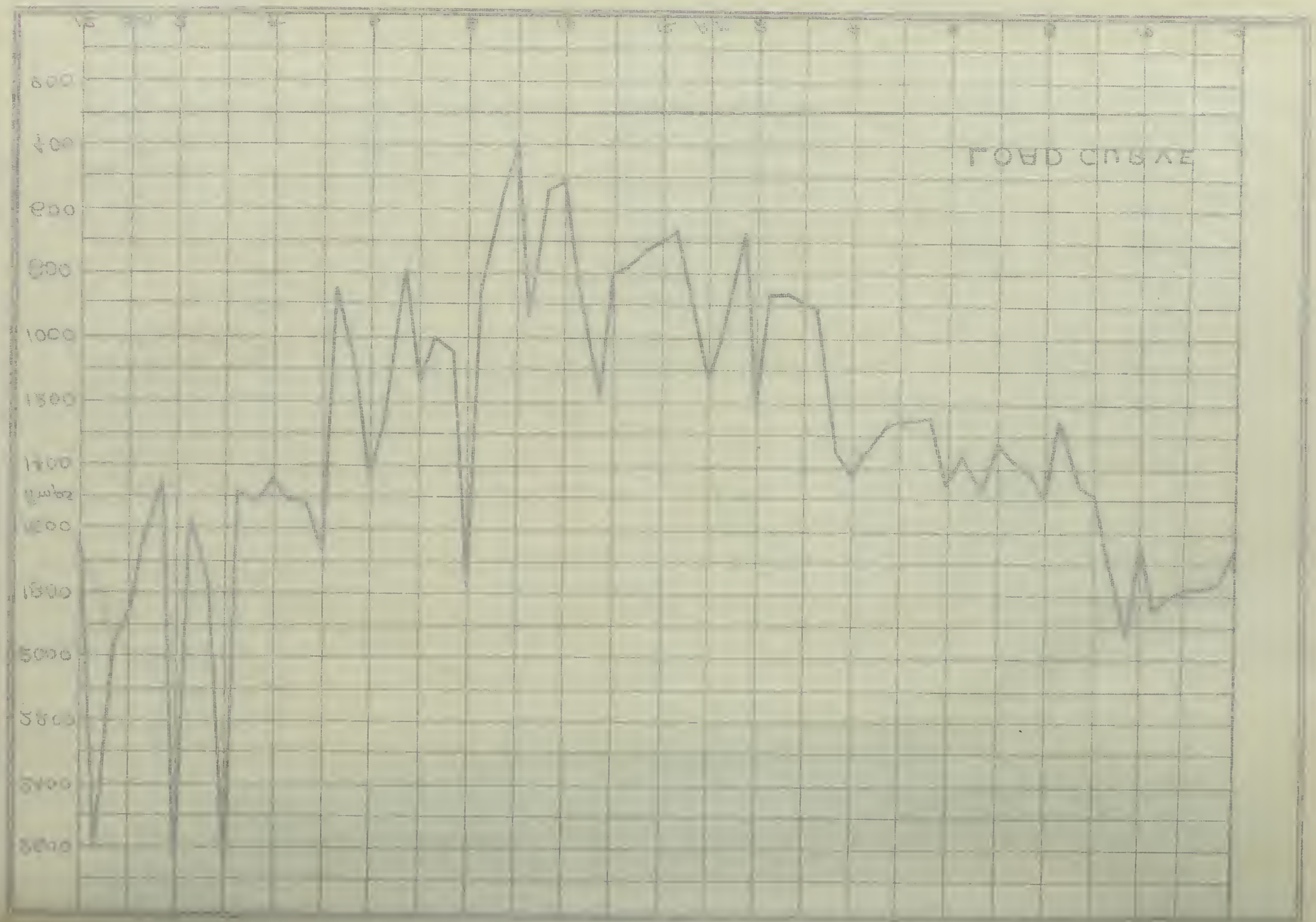
The points on this load curve were gotten as follows: Taking for an example the load at 7 A.M.; starting at the top of the Champaign-Kensington chart and continuing to Twelfth Street.

LOAD-CURRENT CALCULATION FOR 7 A.M.

CLASS	WEIGHT	NO.	CONDITION	CURRENT OF EACH	TOTAL CURRENT
PASSENGER	700	2	RUNNING	52 AMPS.	104 AMPS.
FREIGHT	990	2	"	85 "	170 "
"	1880	2	"	95 "	190 "
"	1370	1	"	67 "	67 "
"	3050	1	"	234 "	234 "
Passenger	700	2	"	52 "	104 "
Freight	990	1	STARTING	164 "	164 "
			TOTAL CURRENT		1,130 AMPS.

The load was calculated for every twenty minutes in a similar way to the above. The load curve was then integrated and the area of it found, the value of the mean ordinate being gotten by dividing the area of the diagram by its length. The area was found to be 117.72 square inches and the length 18 inches thus giving a mean ordinate of 6.546 inches. The scale of the load curve was chosen so one inch was equal to 200 amperes. The mean current is


2600
2400
2200
2000
1800
1600
Amps.
1400
1200
1000
800
600
400
200
12 A.M. 2 4 6 8 10 12 P.M 2 4 6 8 10 12
LOAD CURVE


LOAD CHANGE

6.546 X 200 = 1309.2 amperes.

The maximum load occurs at 3 A.M. and is 2640 amperes. From this the load factor was found to be 1309/2640 or 49.6%.

In order to determine the capacity of the machinery of the transmission and distribution system a polar current diagram was drawn from the load graph, using the same scale. From this polar diagram the mean effective current was found according to the following method:

Area of polar diagram 123.75 sq. in.

Radius of an equal circle, $r, = \frac{2 \times 123.75}{3.1416}$

=8.89 in.

Scale 1 in. = 200 amps.

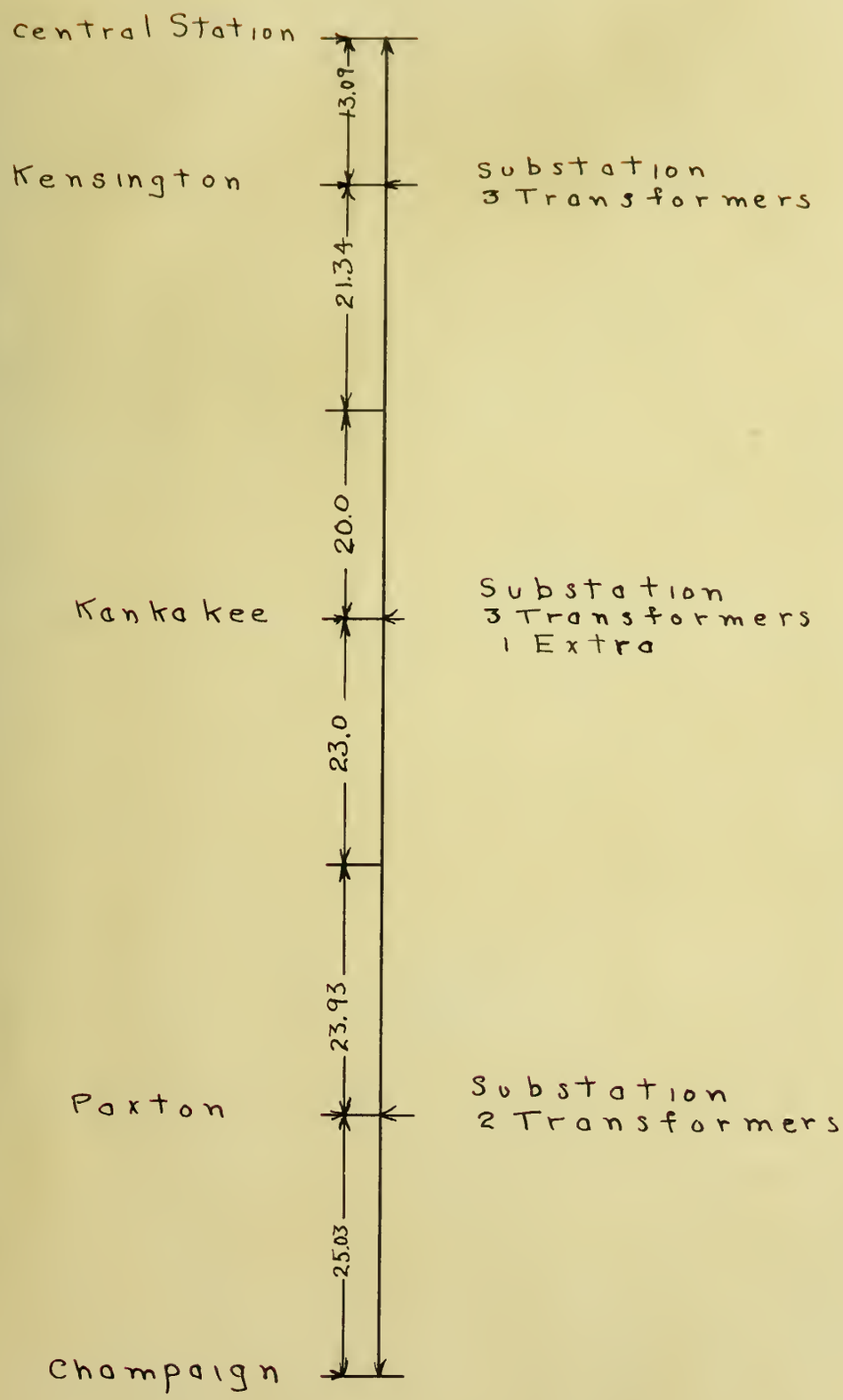
Mean effective current, I,=200 X 8.89=1778 amps.

E.M.F. 11,000 volts. Average power factor =.81

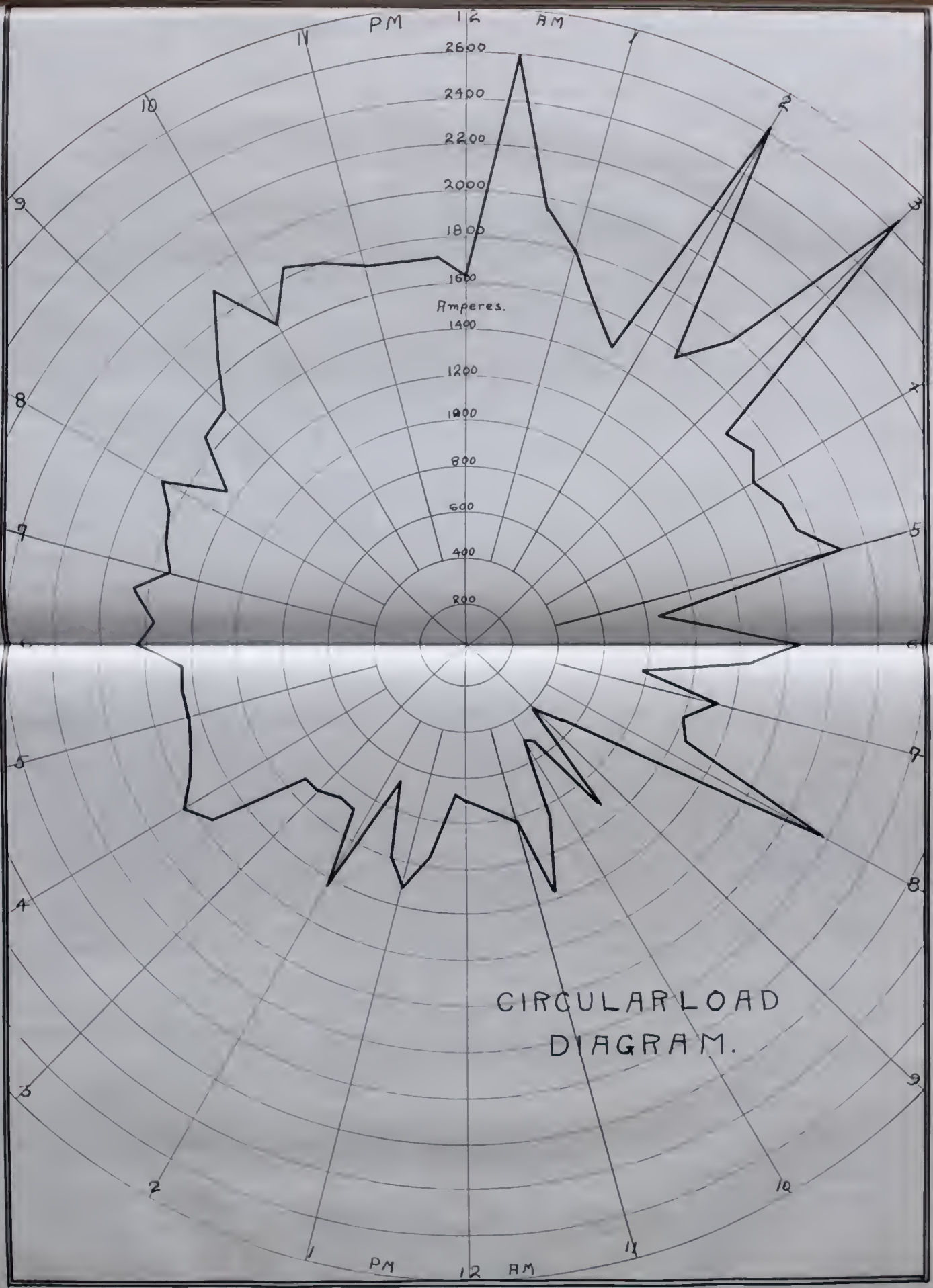
Actual power=1778 X 11,000 X .81=15,850 kw.

The polar current diagram was used to get the mean effective current , because it is the simplest and the most accurate method. For the theory and use of the polar current diagram see this reference by C.O. Mailloux, Transactions International Electrical Congress, Turin, 1911.

The power used on this electrified division was taken to be 16,000 kw. Eight transformers of 2,000 kw. each will be used to reduce the transmission potential and they will be distributed as follows; three at Kensington, four at Kankakee including one for reserve, and two at Paxton.


central Station
13.09
Kensington
Substation
3 Transformers
21.34
20.0
Kankakee
Substation
3 Transformers
1 Extra
23.0
23.93
Paxton
Substation
2 Transformers
25.03
Champaign

CARDIOID
CIRCULAR-CARDIOID



CIRCULAR LOAD DIAGRAM.

CHAPTER FIVE

COMPARISON OF STEAM AND ELECTRIC OPERATION

The total cost of the engine service for steam and for electric operation was determined by taking, as a basis, the annual statement of the performance of locomotives of the Illinois Central, for the year ending June 30, 1909. From this table the cost of engine service for 1913 was estimated by using the proportion 1.67, as obtained in the traffic calculations, for the amount of business handled in 1913 as compared to that of 1909.

TOTAL COST OF ENGINE SERVICE FOR THE CHICAGO DIVISION

	1909	1913
Enginemen	$661,963	$1,108,000
Roundhouse men	308,018	348,000
Fuel	737,533	1,234,000
Oil, tallow and waste	32,234	54,100
Other supplies	6,799	11,390
Engine maintenance	274,951	461,000
Shop maintenance	493,010	825,000
TOTAL	$2,414,508	$4,041,490

The total cost of the engine service for the Champaign-Chicago section was taken as 38% of the cost of engine service for the entire Chicago division for the year 1913.

COST OF ENGINE SERVICE FOR THE CHAMPAIGN-CHICAGO DIVISION

	Steam -1913-	Electric
Enginemen	$421,000	$421,000
Roundhouse men	132,200	53,000
Fuel	469,000	566,064
Oil, tallow and waste	20,560	13,510
Other supplies	4,325	4,325
Engine maintenance	175,200	87,600
Shop maintenance	313,500	156,750
Cost of handling foreign trains	59,000	
TOTAL	$1,594,785	$1,302,249

The cost of the electric service for 1913 was calculated from the cost of steam engine service for the same period by means of the comparative tables and percentages given on page 20 of Stillwell and Putnam, "Substitution of the Electric Locomotive for the Steam Locomotive", Proceedings of the A.I.E.E., Jan. 25,1907.

Although the substitution of the electric for the steam locomotive eliminates the work which the fireman performs, and thus makes necessary the use of only one man per locomotive, the railroads which have undertaken electrification have found it advisable to keep two men upon their engines. The engineers' and firemen's unions require that two men be retained on the electric locomotives and that no reduction in pay be made due to the change of operation. The fact that the operation of electrical equipment is much easier

than that for steam, and the time required for apprenticeship shorter does not lower the standard of character and judgment of the enginemen required. Thus no saving in expense results from electrification, in this item.

The outlay required for roundhouse men in electric service has been taken as 40% of that necessary on a steam railroad.

The cost of power for the electrified service was found to exceed the present cost of fuel for steam operation as calculated from the available data. This increase in cost is partly due to the increase in traffic which is contemplated in the electrification, and the assumption that the power will be bought from the Commomwealth Edison Company at the existing rate, when it is no more than probable that a reduction in this rate can be obtained for the reasons stated on page 4.

The item of oil, tallow and waste will be considerably lower after electrification and was assumed to be 67.5% of that for steam.

No reduction has been made in the item "Other Supplies", in order to allow for additional or new expenses due to electric operation.

The maintenance of the engines will be lowered about 50% after the installation of the electrical equipment. For it is a well known fact that the maintenance of electric locomotives is only one-half of that for steam; because of the

absence of reciprocating parts and the reduction of the number of rotating and movable elements together with the simplicity of the equipment.

Due to the small number of electric locomotives needed, their low cost of maintenance and repair, the expense of shop equipment will be only 50% of the steam railroad shop machinery.

As the cost of the fuel considered in the estimate on electric operation includes handling the Michigan Central and the C.C.C.&St.L. trains, it is not more than right that this should also be charged to steam operation. From the annual report of the Illinois Central on the performance of locomotives for 1909, the cost of handling freight trains was found to be 32.33 cents per 1,000 ton-miles. The foreign trains handled consist not of freight trains but of passengers; however owing to the fact that there is no further information available for passenger trains it will be assumed that it costs the same to handle the passenger as it does the freight trains at the low speeds permissible within the city of Chicago. The daily ton-miles for the Michigan Central and the C.C.C.&St.L. trains is 501,780. The annual cost of handling these trains will be

501,780 X .3233 X 365 / 1,000 = $59,000.

With $59,000 added to the cost of engine service for 1913 makes a total of $1,494,785. The difference in favor of electric operation is $1,494,785 - $1,302,249 or $192,536.

The method used in the calculation of the cost of the power will now be shown. The morning peak load comes, on the Commonwealth Edison power plant, between the hours of 7 and 8 A.M. and the evening load occurs between the hours 5 and 6 P.M. (From the Electric Railway Journal, March 7, 1914). The average of the morning peak load is 1170 amperes and the average evening peak is 1300 amperes at 11,000 volts, as found from our load curve. The average of the morning and evening peak loads is 1235 amperes. The voltage being 11,000 and the power factor .81 the total power is;

1235 X 11,000 X .81 = 11,000 kw.

The primary cost of power per month is at $1.25 per kw.

11,000 X $1.25 = $13,750.

The primary cost per year is

$13,750 X 12 = $165,000

Secondary Charge

The average current as found by means of the current-time curve is 1309 amperes.

The average power is

1309 X 11,000 X .81 = 11,663 kw.

The average power per month is

11,663 X 24 X 30 = 8,398,160 kw.hrs.

Cost of the first 5,000,000 kw.hrs. @$0.004 is $20,000 per month.

Cost of the remaining 3,398,160 kw.hrs. @ $ 0.00395 per month is $13,422.

Total cost of power per month is $20,000+ $13,422 = $33,422.

Cost of power per year is

$$\$33,422 \times 12 = \$401,064$$

Total cost of power per year including primary charge is

$\$165,000 + \$401,064 = \$566,064.$

CHAPTER SIX

COST OF INSTALLATION

The cost of the purchase of, the installation and the erection of the electrical equipment for the Champaign-Chicago division of the Illinois Central is shown in the following paragraphs.

The cost of the transmission line was calculated as follows:

All power used on this electrified division will be transmitted to the transformer substations at a pressure of 60,000 volts, by means of a three-wire single phase system.

Feeders to Kensington substation.

Capacity of station 3 - 2,000 kw. transformers.

I = 600,000/ 6,000 = 100 amps.

#3 wire will carry 110 amps.

Resistance of #3 wire = .2 ohms per 1,000 ft.

Distance to Kensington = 69,200 ft.

Total resistance = 69,200/ 1,000 X .2 = 13.84 ohms.

Resistance drop IR = 100 X 13.84 = 1384 volts.

Per cent drop = 1384/ 60,000 = 2.3%.

Weight of #3 wire per 1,000 ft. = 159.3 lbs.

Total length of wire 3 X 69.2 = 207.6 thousand feet.

Total weight of feeder wire = 159.3 X 207.6 =

33,070 lbs.

Cost of copper per lb.= 17 cents.

Total cost of feeders to Kensington 33,070 X 17=$5621.90

Feeders to Kankakee substation.

Capacity of station=3 -2,000 kw. transformers.

I = 600,000 / 6,000=100 amps.

Distance to Kankakee = 283,000 ft.

Use #0 wire, which has .1 ohm resistance per 1,000 ft.

Total resistance =.1 X 283=28.3 ohms.

Total drop=100 X 28.3 2830 volts.

Per cent drop=4.72%.

Weight of wire per 1,000 ft.= 391.5 lbs.

Total weight of wire = 3 X 391.5 X 283=333,000 lbs.

Total cost of copper @ 17¢ per pound=333,000 X .17 = $56,500.

Feeders to Paxton subststion.

Capacity of station 2 -2,000kw. transformers.

I = 4000,000/ 6,000= 67 amps.

Distance to Paxton = 533,280 ft.

#6 wire would carry the current, but its resistance is too great; therefore #0 wire will be used, which has a resistance of .1 ohm per 1,000 ft.

Total resistance = 533.3 X .1 = 53.3 ohms.

Resistance drop IR 53.3 X 67 = 3850 volts.

Per cent drop = 3580/ 60,000 = 5.97%.

Weight of #0 wire is 391.5 lb. per 1,000 ft.

Total weight of wire = 391.5 X 533.3 X 3 = 626,358 lbs.

Total cost of wire @ 17¢ per lb. = 626,358 X .17 = $106,480.

Total cost of all wire in the transmission line is:

$106,480
5,620
56,500
$168,600

The following is an estimate of the cost of the steel trolley contact wire, using #0000 steel wire.

Specific gravity of steel is 7.9.

Specific gravity of copper is 8.95.

Weight of #0000 copper wire per 1,000 ft. is 640.5 lbs.

Weight of steel wire per 1,000 ft. = 7.9/ 8.95 X 640.5 = 565 lbs.

Length of single track = 306.0 miles = 1615700 ft.

Total weight of contact wire = 1615.7 X 565 = 912,870 lbs.

Total cost of wire @ 6.25¢ per pound = 912,870 X .0625 = $57,054.

The cost of the transformers was calculated by means of Prof. E.H. Waldo's equation;

Cost = 1.4(439 + 1.467 X kva.)

Cost of the eight transformers @$4,722 each

8 X 4,722 = $37,776.

The cost of the towers and supporting structure for the contact and transmission lines was based upon the following calculations:

Poles spaced every 300 feet, will require the use of 4,182 poles 35 feet high, with 7 in. top and 9 in. bottom, which will be of tublar steel at $28 each.

Cost of poles = 4,182 X 28 = $117,096.

Placing anchor towers at every half-mile will require 252 at a cost of $2300 each.

Cost of anchor towers = 252 X 2300 = $597,600.

The steel cable that will be used for messenger and guy wire is 3/8 inches in diameter, which costs $6.28 per 1,000 feet.

Trolley support requires	1,330,000	ft.	of	wire
Cross catenary "	70,000	"	"	"
Anchors and braces "	50,000	"	"	"
Total length of wire	1,450,000	ft.		

Cost of wire = 1,450 X 6.28 = $9,000.

The number of trolley bars and hangers that will be necessary is 4,434 and the cost of each is 65¢ complete.

Cost of trolley hangers complete=4,434 X .65= $2,882.

Cost of 4,440 cross-arms @ $1.50 each = 4,440 X 1.50 = $6,660 .

Hardware, insulators and miscellaneous=$10,000.

Total cost of supporting structure = $ 743,238.

The estimate on the cost of rail bonds is based on 33 ft. rails and the bonding of only one rail per track, with cross bonds distributed the entire distance.

Total length of track = 1,615,000 ft.

Number of bonds 1,615,000/ 33 = 48,960 bonds.

From the Standard Handbook the bonds cost $0.70 and the cost of installation is $0.55 each making a total cost of $1.25 per bond.

Total cost of bonds = 48,960 X $1.25 = $61,200.

Allowing $5,000 to bond the tracks together the total cost of track bonding will be $66,200.

The total cost of installing the electrical equipment is shown in the following table:

COST OF ELECTRIFYING

Transmission Line	$ 37,776
Transformers	168,602
Trolley Wire	57,054
Track Bonding	66,200
Poles and Supporting Structure	743,238

Shop Equipment	$ 50,000
Locomotives, Passenger, 15 @ $35,000	525,000
" , Freight, 14 @ $50,000	700,000
" , Switching, 3 @ $20,000	60,000
TOTAL	$2,410,270

In calculating the number of locomotives necessary to handle the traffic on the electrified division a lay-over of two hours was allowed after each run before putting the locomotive into service again. Where it was found possible the freight locomotives were used to handle the local passenger traffic,in order to reduce the number of runs made by"light"freight locomotives.

The interest on the investment required to electrify the Champaign-Chicago division is shown below:

Interest per year at 4.5%	$108,500
" " " " 5.0%	120,700
" " " " 5.5%	132,800

CHAPTER SEVEN

—

CONCLUSION

The advantages that can be derived from the electrification of the Champaign-Chicago division of the Illinos Central Railroad are shown in the following:

The physical advantages to be derived from electrification are increased traffic capacity, greater flexibility, simplicity, reliability and improvement of service.

The financial advantages occur from the increase in gross earnings due to increase of terminal capacity, better motive power characteristics, increased comfort of passengers, frequent train service,and the decrease in cost of operation due to the saving in maintenance, time and wages.

The immediate financial advantage that can be gotten from the electrified service is shown by the great decrease in the cost of engine operation. The present cost of engine service on this section of the Illinois Central for steam power is $1,494,785; while the cost of electric engine service is only $1,302,249. To this latter item must be added the interest on the investment necessary to electrify the division.

The following table shows the annual saving that can be obtained from the electrification of this section, the calculations were made with the three current rates of interest, and the net saving for each case is shown.

RATE OF INTEREST	INTEREST ON INVESMENT	COST OF ENGINE SERVICE STEAM	ELECTRIC	SAVING DUE TO ELECTRIFICATION
4.5%	$108,500	$1,494,785	$1,302,249	$84,036
5.0	120,700	"	"	71,836
5.5	132,800	"	"	59,736

Although the switching service in the Chicago yards and the suburban service were not considered in this thesis, the report by Mr. W.S.Murray on the New Haven switching locomotives in the Electric Traction of March 7, 1914, proves conclusively that the expense of yard switching can be reduced one-half by electric operation. The electrification of the suburban services of the New York, New Haven and Hartford, the Pennsylvania and the New York Central Railroads prove the necessity and advisability of electric motive power for this kind of traffic.

Therefore we consider it highly desirable that the Illinois Central Railroad electrify its right-of-way between the city of Champaign and the Twelfth Street Terminal, Chicago, with the single-phase system and equipment specified in the preceeding pages of this thesis.

APPENDIX A

—

RAILWAY POWER CONTRACT

The following is a copy of the contract between the Commonwealth Edison Company and the Street and Elevated Railways of the city of Chicago for the purchase of power from the former by the latter, as reported in the Electric Railway Journal and the Electrical World for November 29, 1913.

The maximum demand which the Commonwealth Edison Company may be called upon to supply for any month is calculated from the heaviest hourly morning and evening loads on three consecutive days so selected as to yield a total energy consumption for the six hours, greater than would be obtained as the total of the corresponding six hours on any other three consecutive days. The Edison Company must be ready to supply a maximum demand of 20,000 kw., or one equal to that established by the loads of previous months, if they exceed 20,000 kw. To provide for the extra power required for the heating of the cars in extremely cold weather, the "emergency energy" consumed when the temperature is at or below 15 degrees Fahrenheit is excluded in determining the maximum demand.

PRICES OF ENERGY

PRIMARY OR POWER CHARGE

MAXIMUM DEMAND IN KW.	PRIMARY CHARGE IN KW.
To and including 30,000	$1.25

MAXIMUM DEMAND IN KW.	PRIMARY CHARGE IN KW.
Excess over 30,000 to and including 60,000	$1.00
" " 60,000 " " " 90,000	0.916
" " 90,000 " " " 120,000	0.875
" " 120,000	0.833

SECONDARY OR ENERGY CHARGE

MONTHLY ENERGY CONSUMPTION IN KW.-HR.	CHARGES PER KW.-HR. IN FRACTIONS OF A CENT
To and including 5,000,000	0.400
Excess over 5,000,000 to and including 10,000,000	0.395
" " 10,000,000 " " " 15,000,000	0.390
" " 15,000,000 " " " 20,000,000	0.385

These charges are subject to a correction for the price of coal. If during any two-year period the price of coal, having a heating value equivalent to that of coal from the mines of central Illinois, delivered at the storage yards of the Edison company exceeds on the average $1.90 per ton, the railway company shall pay an extra charge to cover this excess. The correction in dollars is obtained by dividing by 1,000 the number of kilowatt-hours delivered during the two-year period and multiplying this by the excess price of the coal. This calculation is obviously made on the basis of a payment by the railway company of 2 lb. of coal per kilowatt-hour. That is

Excess cost of coal (2 X kw.-hr./ 2000) X cost - $1.90.

On the other hand , if the cost of the coal is less than $1.40 per ton the lighting company is to pay the railway company a sum calculated as described.

The railway company has agreed to generate no electrical energy during the period Nov. 1, 1914 to Jan. 31, 1924, but reserves the right to do so after that date. In doing so,however, it is provided that the Edison power shall be used in such amount as shall insure an average monthly load equal to 35 per cent of the amount which the lighting company must, under contract, stand ready to supply.

APPENDIX B

COST OF POWER IF GENERATED BY RAILWAY

The annual cost of power if the railway builds its own power plant, will be as follows:

Average power required = 16,000 kw.

Maximum power demand = 23,200 kw.

The power plant can easily carry this overload as it occurs for less than five minutes.

Cost of power plant at $85 per kilowatt = 85 X 16,000
= $1,360,000.

Interest and depreciation at 10% = $136,000

Average annual power = 100,800,000 kw.-hrs.

Cost per kw.-hr = 0.5¢.

Annual cost of power = 0.005 X 100,800,000 = $504,000.

Total cost of power per year = $136,000 + $504,000
= $640,000.

Annual cost of purchased power = $401,064.

Saving due to purchase of power = $504,000 - $401,064
= $102,936.

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